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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Docket No.:	SL-1225-00P

This is a request for filing a PROVISIONAL APPLICATION under 37 C.F.R. §1.53 (c).

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Title of the Invention

PV PERFORMANCE MONITOR

Enclosed are:

[X] 5 sheets of drawings.

[X] 33 pages of specification.

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PV PERFORMANCE MONITOR

Technical Field

This invention relates to the general subject of methods and apparatus for converting sunlight into electricity, and, in particular, to methods and apparatus used to display the performance of a photovoltaic power supply.

CROSS-REFERENCE TO RELATED APPLICATIONS

Not applicable

STATEMENT REGARDING FEDERALLY - SPONSORED RESEARCH OR DEVELOPMENT

Not applicable

REFERENCE TO A "MICROFICHE APPENDIX

Not applicable

Background of the Invention

The photovoltaic (PV) module is the basic building block of PV electrical systems. A PV module is composed of interconnected cells that are encapsulated between a glass cover and weatherproof backing. The modules are typically framed in aluminum frames suitable for mounting. The term "solar panel" is often used to refer to a PV module. However, the same expression is also used in reference to solar water heating systems, so to avoid confusion, "photovoltaic module" is preferred.

Among other things, the performance of a PV module depends on the cell material. The conversion efficiency of amorphous silicon modules varies from 6 to 8%. Modules of multi-crystalline silicon cells have a conversion efficiency of about 15%. Mono-crystalline silicon modules are the most efficient; their conversion

efficiency is about 16%. Typical sizes of modules are 0.5 x 1.0 m2 and 0.33 x 1.33 m2, made up of about 36 PV cells. However, modules of any desired size can be produced. The modules have a transparent front sheet, which is glass or plastic. The back can be opaque. Glass and Tedlar, a plastic that is available in both transparent and opaque, are frequently used. Because of the aforementioned properties of amorphous silicon, modules of this material can have various forms and sizes, though most of the commercially available modules are rectangular and composed like the crystalline ones. Furthermore, amorphous silicon can be deposited on, e.g., windows, metal sheets, plastics and roof tiles.

Standard rectangular modules can be delivered with or without frame. Frameless modules, or laminates, can essentially be processed as normal glass panes. Special attention has to be paid to water tightness, cabling, and shading of the module surface. The thickness of glass-Tedlar laminates is generally 8 mm. Glass-glass laminates are generally at least 10 mm thick.

PV modules are connected in series and parallel to form an array, thus increasing total available power output to the needed voltage and current for a particular application. For connecting the PV modules either in series or parallel, most PV modules are equipped with a junction box at the rear side. These boxes are, in general, 5 to 7 cm deep. In larger PV power systems, PV arrays are connected either in series or parallel again, depending on the required input power of the selected inverter.

The electrical current generated by photovoltaic devices is influenced by the spectral distribution (spectrum) of sunlight. It is also commonly understood that the spectral distribution of sunlight varies during the day, being "redder" at sunrise and sunset and "bluer" at noon. The magnitude of the influence that the changing spectrum has on performance can vary significantly, depending on the photovoltaic technology being considered.

In any case, spectral variation introduces a systematic influence on performance that is time-of-day dependent. Similarly, the optical characteristics of photovoltaic modules or pyranometers can result in a systematic influence on their performance related to the solar angle-of-incidence.

Factors Affecting Output

The factors that affect the output of a solar power system should be understood so that a user has realistic expectations of overall system output and economic benefits under variable weather conditions over time. The amount of useful electricity generated by a PV module is directly generated to the intensity of light energy, which falls onto the conversion area. So, the greater the available solar resource, the greater the electricity generation potential. The tropics, for instance, offer a better resource for generating electricity than is available at high latitudes. It also follows that a PV system will not generate electricity at night, and it is important that modules are not shaded. If electricity is required outside daylight hours, or if extended periods of bad weather are anticipated, some form of storage system is essential.

Standard Test Conditions

Solar modules produce DC electricity. The DC output of solar modules is rated by manufacturers under Standard Test Conditions (STC). These conditions are easily recreated in a factory, and allow for consistent comparisons of products, but need to be modified to estimate output under common outdoor operating conditions. STC conditions are: solar cell temperature = 25° C; solar irradiance (intensity) = 1000 W/m2 (often referred to as peak sunlight intensity, comparable to clear summer noon time intensity); and solar spectrum as filtered by passing through 1.5 thickness of atmosphere (ASTM Standard Spectrum). A manufacturer may rate a particular solar module output at 100 Watts of power under STC, and call the product a "100-watt solar module". This module will often have a production tolerance of +/-5% of the rating, which means that the module can produce 95 Watts and still be called a "100-watt module". To be conservative, it is best to use the low end of the power output spectrum as a starting point (95 Watts for a 100-watt module). Fig. 1 is a graphical presentation of the current versus the voltage (I-V curve) from a photovoltaic cell as the load is increased from the short circuit (no load) condition to the open circuit (maximum voltage) condition. The shape of the curve characterizes cell performance; this can be called "factory performance" or performance of a PV cell under ideal conditions.

Temperature

Module output power reduces as module temperature increases. When operating on a roof, a solar module will heat up substantially, reaching inner temperatures of 50-75 Cº. For crystalline modules, a typical temperature reduction factor recommended by the CEC is 89% or 0.89. Therefore, the "100-watt" module will typically operate at about 85 Watts (95 Watts x 0.89 = 85 Watts) in the middle of a spring or fall day, under full sunlight conditions. To ensure that PV modules do not overheat, it is essential that they are mounted in such a way as to allow air to move freely around them. This is a particularly important consideration in locations that are prone to extremely hot midday temperatures. The ideal PV generating conditions are cold, bright, sunny days.

Dirt and dust

Dirt and dust can accumulate on the solar module surface, blocking some of the sunlight and reducing output. Much of California has a rainy season and a dry season. Although typical dirt and dust is cleaned off during every rainy season, it is more realistic to estimate system output taking into account the reduction due to dust buildup in the dry season. A typical annual dust reduction factor to use is 93% or 0.93. Therefore, the "100- watt module," operating with some accumulated dust may operate, on average, at about 79 Watts (85 Watts x 0.93 = 79 Watts).

Mismatch and wiring losses

The maximum power output of the total PV array is always less than the sum of the maximum output of the individual modules. This difference is a result of slight inconsistencies in performance from one module to the next, and is called "module mismatch" and can amount to at least a 2% loss in system power. Power is also lost to resistance in the system wiring. These losses should be kept to a minimum but it is often difficult to keep these losses below 3% for the system. A reasonable reduction factor for these losses is 95% or 0.95.

DC to AC conversion losses

The dc power generated by the solar module must be converted into common household ac power using an inverter. Some power is lost in the conversion process, and there are additional losses in the wires from the rooftop array down to the inverter and out to the house panel. Modern inverters commonly used in

residential PV power systems have peak efficiencies of 92-94% indicated by their manufacturers, but these again are measured under well-controlled factory conditions. Actual field conditions usually result in overall dc-to-ac conversion efficiencies of about 88-92%, with 90% or 0.90 a reasonable compromise. So the "100-watt module" output, reduced by production tolerance, heat, dust, wiring, ac conversion, and other losses will translate into about 68 Watts of AC power delivered to the house panel during the middle of a clear day (100 Watts x 0.95 x 0.89 x 0.93 x 0.95 x 0.90 = 67 Watts).

Estimating System Energy Output

Sun angle and house orientation

In order to capture as solar energy as possible, the photovoltaic cell must be oriented towards the sun. If the photovoltaic cells have a fixed position, their orientation with respect to the south (northern hemisphere), and tilt angle, with respect to the horizontal plane, should be optimized. The optimum tilt angle lies within a range of approximately 15 degrees of the site latitude. For grid-connected PV systems in Western Europe, for instance, the optimum tilt angle is about 35 degrees. For regions nearer to the equator, this tilt angle will be smaller, and for regions nearer to the poles, it will be larger. A deviation of the tilt angle of 30 degrees from the optimum angle, will lead to less than 10% loss of the maximum yield. During the course of a day, the angle of sunlight striking the solar module will change, which will affect the power output. The output from the "100-watt module" will rise from zero gradually during dawn hours, and increase with the sun angle to its peak output at midday, and then gradually decrease into the afternoon and back down to zero at night. While this variation is due in part to the changing intensity of the sun, the changing sun angle (relative to the modules) also has an effect

The pitch of the roof will affect the sun angle on the module surface, as will the East-West orientation of the roof. These effects are summarized in **Table 1**, which shows that an array on a 7:12-pitch roof facing due South in Southern California gives, for example, the greatest output (correction factor of 1.00), while an East facing roof at that same pitch would yield about 84% of the annual energy of the South facing roof (a correction factor of 0.84 from **Table 1**).

	Flat	4:12	7:12	12:12	21:12	Vertical
South	0.89	0.97	1.00	0.97	0.89	0.58
SSE, SSW	0.89	0.97	0.99	0.96	0.88	0.59
SE, SW	0.89	0.95	0.96	0.93	0.85	0.60
ESE, WSW	0.89	0.92	0.91	0.87	0.79	0.57
E, W	0.89	0.88	0.84	0.78	0.70	0.52

TABLE 1: Orientation Factors for Various Roof Pitches and Directions

CITY	kWh/kWstc (range)
Arcata	1092 - 1365
Shasta	1345 - 1681
San Francisco	1379 - 1724
Sacramento	1455 - 1819
Fresno	1505 - 1881
Santa Maria	1422 - 1778
Barstow	1646 - 2058
Los Angeles	1406 - 1758
San Diego	1406 - 1758

TABLE 2: Annual Energy Production by City per kW STC array rating

Table 2 is intended to give a conservative estimate of the annual energy expected from a typical PV system, taking into account the various factors discussed above. These values are for annual kWh produced from a 1-kilowatt (1kW) STC DC array, as a simple and easy guide.

<u>Example:</u>

A 4 k WSTC solar array (as specified under STC conditions) located in the Los Angeles area at a 4:12 pitch and facing southeast should produce at least 5343 kWh of electric energy annually (1406 kWh/kW x 0.95 x 4 kW = 5343 kWh). The typical residential customer in that area uses about 7300 kWh annually1, meaning such a PV system could produce at least 75% of the total energy needed by such a typical home. Moreover, if energy efficiency measures were taken by the owner to reduce the overall electrical consumption of the home, the percentage could approach 100%. Note that the low end

of the range was used to calculate the actual savings. It is wise to be conservative when making performance claims.

Maximum power output of most properly installed PV systems occurs near midday on sunny days in the spring and fall. If the owner fully understands this characteristic, they will not be disappointed with unavoidable low output in the middle of the winter. Metering is a way of proving to the owner that the equipment is properly installed. Often, the owner's primary indication of whether they feel the system is operating properly or not is their monthly electric bill. If the owner suddenly begins using more electricity, they may not see much decrease in their bill and assume the PV system is under-performing. Metering can help avoid disputes between the installer and the owner by showing that the system performs as advertised. One of the attractive attributes of PV system is low maintenance. However, even electrical systems need to be maintained from time to time. With proper metering, an informed owner can easily determine if their system is operating properly or not.

This problem has existed for some time. Considerable effort has been made, and significant amounts of money have been expended, to resolve this problem. In spite of this, the problem still exists. Actually, the problem has become aggravated with the passage of time because solar power systems are becoming more common and are being owned by consumers who do not know subtle solar engineering design factors.

Summary of the Invention

In accordance with the present invention, a method and apparatus is disclosed for monitoring the performance of a solar powered electrical supply for an electrical load wherein the supply comprises an array of photovoltaic cells that are mounted on a building and that have a predetermined performance. In one embodiment, the apparatus comprises: irradiance means, in solar communication with the array, for producing a signal representative of solar irradiance; computation means, carried by the building and having a clock, for computing a running performance signal by using at least the predetermined performance rating, the

irradiance signal, and a measure of the electrical power supplied to the load from the array; a radio for broadcasting the performance signal; and a portable unit for receiving the performance signal from the radio and for visually displaying the performance signal.

The invention analyses electrical grid connected PV system performance in real time, using empirical formulae to ensure that it is working correctly, and, in the event of a performance limiting fault, it can send a message to report the problem. Such empirical formula reflect real-world performance as opposed to theoretical performance which is rarely achieved.

In another embodiment, the array is characterized by a tilt, an azimuth, an outdoor temperature, and a geographic location; and the computational means computes a running performance signal by using the irradiance signal, the predetermined performance rating, the measure of the electrical power supplied to the load from the array, and at least one of the geographic location of the building, the tilt of the array, the azimuth of the array, and outdoor temperature. The portable unit comprises a plurality of indicators, including: solar irradiance, temperature, time, photovoltaic power production, photovoltaic power relative to utility provided electrical power, photovoltaic power on a time scale, total photovoltaic power production, daily power production, power production relative to utility power consumption, and daily solar production relative to maximum possible production .

The invention provides an improved and efficient method and apparatus for owners of solar power systems to understand what is happening and how their system is performing. Numerous other advantages and features of the present invention will become readily apparent from the following detailed description of the invention, the embodiments described therein, from the claims, and from the accompanying drawings.

Brief Description of the Drawings

FIG. 1 is a graphical depiction of current versus voltage from a PV cell as load is increased;

FIG. 2 is a block diagram of a typical solar electrical power system;

FIG. 3 is a schematic diagram of the Data Display Unit that is part of the subject invention;

FIG's. 4 and 5 are block diagrams of the components of the present invention;

FIG. 6 is a flow chart of performance calculations performed within the Data Collection Unit;

FIG. 7 is an alternative display for solar irradiance display of FIG 3; and

FIG. 8 is a partial assembly drawing of the Data Display Unit showing the bezel and liquid crystal display board coming together.

Detailed Description

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings, and will herein be described in detail, several specific embodiments of the invention. It should be understood, however, that the present disclosure is to be considered an exemplification of the principles of the invention and is not intended to limit the invention to any specific embodiment so described.

Before describing the invention in detail, the environment of the invention will be explained.

Typical System Components:

A typical solar electrical power system (see Fig. 2) comprises: a PV Array, Balance of System Equipment, a DC-AC Inverter, and Metering.

PV Array: Common PV modules are 5-to-25 square feet in size and weigh about 3-4 lbs./ft2. Often sets of four or more smaller modules are framed or attached together by struts in what is called a panel. This panel is typically around 20-35 square feet in area for ease of handling on a roof. This allows some assembly and wiring functions to be completed on the ground if called for by the installation instructions.

DC-AC inverter: This is a device that takes the dc power from the PV array and converts it into standard ac power used by the house appliances.

Balance of System Equipment (BOS): This refers to the mounting systems and wiring systems used to integrate the solar modules into the structural and

electrical systems of the home. The wiring systems include disconnects for the DC and AC sides of the inverter, ground-fault protection, and over current protection for the solar modules. Most systems include a combiner board of some kind since most modules require fusing for each module source circuit. Some inverters include this fusing and combining function within the inverter enclosure.

Metering: This includes meters to provide indication of system output. Some meters can indicate home energy usage.

Other Components: utility switch (depending on local utility)

PV Arrays do not produce the energy expected of them by multiplying their nominal Pmax by the Total Irradiance due to non-linear device performance under

- different Irradiances,
- ambient temperatures,
- spectra,
- system losses, and
- faults.

It can be difficult to predict if they are performing well under different meteorological conditions.

This invention, "PV-Verifier" or "PV²", defines a new way of checking the PV array performance

- to help get the highest kWh out of a system,
- to maximise the usefulness, and
- to reduce the cost/kWh.

Although solar modules are normally sold based on their nominal power at STC (Standard Temperature and Conditions =1000W/m² normal Irradiance at AM1.5G and at a cell Temperature of 25C). However, in real outdoor conditions:

- Irradiance varies from 0 to around 1100W/m²,
- PV cell temperature can be up to 30 C above the ambient temperature,
- Solar spectrum will vary depending on the Solar Zenith Angle and atmospheric conditions, and
- Solar incident angle will depend on the solar position with respect to

the array's tilt and azimuth.

Therefore, an installed PV array will rarely, if ever, give nameplate instantaneous Pmax rating and under most weather conditions will be less.

Previous methods (see Fig. 1) of checking the module and system performance often relied on "correcting back" from as-measured power to STC, usually by:

- using linear coefficients of dI_{sc}/dT, dV_{oc}/dT and dP_{max}/dT and
- assuming a linear dependency on light level.

When PV arrays are installed and used:

- during low light level periods (e.g. winter time), or
- during extreme temperatures, or
- during high solar incidence angles, then

it is difficult to correct back to STC for the modules as errors are largest when the biggest corrections in Temperature and Irradiance are made. There also exists the possibility of system losses due to:

- poor voltage tracking,
- Inverter efficiency,
- wiring loss, or
- some of the PV strings being open circuit.

It also has been difficult to check if the array was set up and performing as expected.

Overview

The invention is intended to monitor and display PV system performance. The present invention consists of two discrete units, interfaced by radio-frequency (RF) link:

- The Data Collection Unit performs data measurement, processing, storage, and transmission via RF link to the Data Display Unit.
- The Data Display Unit visually depicts information transmitted to it from the Data Collection Unit.

[redacted]

- The RF interface is designed to function reliably through exterior and/or interior walls of the residence and at distances up to 80 feet (as limited by the restrictions imposed by the FCC and the physical composition of the individual residential structure).

The units are preferrably packaged separately.. Construction and packaging of both units should be consistent with UPS/FEDEX shipping specifications per ISTA 3C. . Data Collectionand Data Display units may be marked with unique serial numbers for data monitoring and identification.. Complete end-user instructions are provided for installation and use..

<u>Data Collection Unit:</u>

This unit has these functions:

- Measures true AC power out of PV system . Typically, 50A max,. either 120V or 240V electrical service, uses one current transducer located in electrical utility service entrance enclosure.. . For 240V service,. two conductor legs are run through current transducer. .
- Measures true AC power into and out of home at the service entrance. Standard 200 amps(A), Edison 3 wire 240 Vac residential utility service usually requires two current transducers)..
- Measures solar irradiation using an analog sensor located by the solar PV array. For a home this is typically at a distance of up to 100 feet away from the Data Collection Unit..
- Measures ambient temperature using a temperature sensor housed in an enclosure located on the household rooftop.. Tis is typically at a distance of up to 100 feet..

Preferrably the measurement accuracy is +/-2% for power and solar irradiance, 1 degree C for temperature (may be achieved by one-time calibration at setup via RS232 port.). The sampling rate is consistent with refresh rate on Display Unit. A voltage transducer is used for power measurement (i.e.,. monitor either line-to-line

240Vac or one 120 Vac leg). Current transducers for home power measurement may be the "split type" for ease of installation.

Preferrably the Data Collection Unit has a RS-232 port on-board to enable setup/calibration. Depending on available memory, averaged data is stored at 15 minute intervals. On-board memory retains data up to 30 days data storage. Data is time and date stamped. Calibration, data and clock settings are stored in nonvolatile memory.

<u>Specifications for operation of optional modem:</u>

The Data Collection Unit is designed to function without an on-board modem while providing space and functionality if a modem is subsequently installed (i.e., adoption of modem feature without redesign of product, by providing a socket in base design). These considerations would be considered:

- Data is identified by site code.
- Dials out daily to a pre-set number or ISP for upload of data to host database
- Desired dial out schedule is set by host.
- Modem and data transmission speed are consistent with a 60 second (max) transmission time.
- Dial out transmission should drop out if homeowner picks up telephone to make call.
- Dropped-out transmissions should be re-attempted after dial tone is detected.
- Up to 30 days data storage are provided in the event of phone problems or when dial out is interrupted by homeowner.
- Unit clock is reset by host during dial out transmission.

Other specifications on the Data Collection Unit include:

- ♦ outdoor rated, NEMA 3R or equivalent, non-metallic
- ♦ appearance is consistent with other residential service entrance enclosures.

- corrosion resistant finish consistent with 20-year lifetime in outdoor environment.
- mechanical configuration permits all power measurement inputs and unit power to be routed from household service entrance through a single conduit.
- tamper resistant by requiring a tool (e.g. screwdriver) for opening.
- equipment internal to enclosure protected from condensation by design/construction and/or internal heat generation.
- ·inverter independent
- ·temperature and irradiance inputs are routed from roof via a four-conductor cable through a cable gland.
- ·optional phone cable for option modem is routed via cable gland.
- ·power to operate the unit is supplied from AC source in utility service entrance; function may be combined with voltage transducer required for power measurement.
- ·operates from-10 deg C to +55 deg C
- ·operates from 0% to 100% relative humidity
- ·inputs are protected against electrical/lightning-induced surges per IEC 1000-4-5 test level 4
- ·antenna is mounted internally or otherwise protected from mechanical damage.
- contains battery-backed real-time clock/calendar with a lifetime accuracy +/-15 min/year (typically +/-5 min/year) settable without opening enclosure (e.g., via a pair of magnetically operated reed switches).

<u>Display Unit:</u>

This unit receives data wirelessly from the Data Collection Unit. It has these features:

- No visible antenna
- Portable
- Installs in the interior of home (e.g., hangs on the wall)
- AA or 9v battery power (no wire connections) expected minimum

battery lifetime of 6 months

- No user accessible switches or controls
- Display layout per Fig. 3
- Injection-molded enclosure.
- Maximum refresh interval of 10 sec.
- Viewable display dimensions 2" x 7"

The Data Display Unit includes Sunlight Intensity Icons. Four different sized 'suns' arrayed left to right, smallest to largest, with intensity as a percentage to the far right:

- 0-15% blank
- >15-25% 1st sun (smallest)
- >25-50% 2nd sun
- >50-75% 3rd sun
- >75-100% 4th sun (largest or highest irradiance)

FIG. 7 is an alternative display for solar irradiance display of FIG 3.

<u>Data Processing, Storage and Transmission:</u>

Data transmission to Data Display Unit is performed wirelessly. Data transmitted includes:

- PV system output in kW,
- Total consumption in kW (i.e., sum of PV and electrical utility service entrance measurements),
- PV system output/consumption as a percentage,
- Sunlight intensity or solar irradiance, as a percentage of maximum or in the form of "sun icons",
- Outdoor temperature in deg F or C (preferrably, software settable),
- PV system energy production, as kWhrs, over the current calendar day,
- PV system energy production over the current calendar day (i.e., household consumption over the current calendar day as a percentage,
- Graphical presentation of current day's PV system energy production over daylight hours at one hour intervals,

- Time of day in AM/PM or 24 hr (preferrably, software settable)
- Total cumulative energy production of PV system in kWhrs (up to 999999).
- System status based on above data

Preferred Certifications:

- Underwriters Laboratory (UL) listed or recognized.
- Construction and manufacturing are consistent with UL listing
- AC power measurement sensors is UL listed
- Power Supply for Data Collection Unit is UL listed
- Meets FCC requirements..
- Design tested and/or evaluated for proper operation in a household environment with no interference with other household electronic devices.
- Installed in compliance with US National Electric Code
- Compatible with European market (i.e., compatible with CE/IEC requirements)..

Reliability/Warranty

- Design and construction consistent with the 25 year expected lifetime.
- Free from defects in material, workmanship, and function for five years from date of purchase..

Operation and Performance

Referring to Fig. 6 on startup, the PV2 reads values of parameters such as

- latitude and longitude,
- array tilt and azimuth,
- Pmax.stc (and if available)
- Vmax.stc and
- Imax.stc)

from memory. In addition, system constants, such as :

- the percentage of calculated power the system must achieve in order to pass the test, and
- the number of consecutive measurements that fail before a

message is sent, and

- the threshold light intensity below which the pass/fail criteria will not be checked)

are loaded from memory. These values are decided by experience in logging similar systems.

Next, it loads typical empirical coefficients for determining the likely array output as a function of instantaneous $I_{irradiance}$ and $T_{ambient}$. Knowing the clock time, the latitude, longitude and array orientation, the maximum expected clear sky irradiance on the array can be inferred. If the Vdc and Idc are known, then these can be checked against input limits and empirical equations to make sure the system is tracking properly. If the irradiance is above a predefined threshold, then the system calculates the expected output power from an empirical equation.

For example the following is an example, written in ______, of the coding to perform this assessment:

```
// Define constants
Pmax = 10 // kWp
A = 0.8
B = 0.1
C = -0.0045
E = 1
Fail = 0.5 // you need at least this to pass
Dark = 0.2 // suns
Fails_in_a_row = 5

// Every measurement
Get Gi // solar irradiance
Get Tam // ambient temperature
Get Pac // measured AC power output Pac

Ycalc = Gi * (A + B*Gi + C*Tam) - E

//Check Gi, Tam, Pac are valid

If Gi > Dark
      If Pac/Pmax < Ycalc * Fail then
            Fails++
                  Passes = 0
                  If Fails >> Fails_in_a_row then SYSTEM DOWN
      else
            Passes++
                  Fails = 0
                  If Passes >> Fails_in_a_row then SYSTEM BACK ON
```

This occupies just a couple of kB of code. You can interpret `C*Tam` as a thermal

derating factor (e.g., -.5%/deg C). "A" is a linear parameter that dominates the computation (e.g., about 0.8 to 1.0). "B" is non-linear parameter. Adding a term for wind speed and a term for a constant loss can further refine performance.

The date, time, Irradiance, $T_{ambient}$ and P_{ac} are read at each measurement of the system. Optionally, wind speed, Vdc and Idc can be stored if available. Many of the values are stored in arrays by different times of day, month, Irradiance or Ambient Temperature bin. These build up over a period of time to let the array "learn" about its performance.

The system can be set up to calculate daily averages and send these to an engineer, or to store monthly averages to enable the data a interrogated via modem line. The effect of shadowing or problems such as inverter startup in the morning can be determined by the system analysing: the shapes of the irradiance (time of day, month) and yield (time of day, month) arrays. If the system had been working, then a predefined succession of failures will flag an error signal that will be sent to an engineer. Similarly if the array comes back on line then a succession of pass measurements will cause a pass signal to be sent.

The invention provides the model from actual measured data. One can start out by using the data from a system that uses similar hardware for validation, but you can soon switch to using past data from the system itself to check performance.

From the foregoing description, it will be observed that numerous variations, alternatives, and modifications will be apparent to those skilled in the art. Accordingly, this description is to be construed as illustrative only and is for the purpose of teaching those skilled in the art the manner of carrying out the invention. Various changes may be made in the shape, materials, size and arrangement of parts. For example, a generally rectangular tall display is shown in Fig. 3; a generally horizontal display may be used as well. Moreover, equivalent elements may be substituted for those illustrated and described. Parts may be reversed and certain features of the invention may be used independently of other features of the invention. As another example, the computer clock may not be correctly set to solar time, and as the irradiance checking relies on this, then the shape of the daily irradiance may be used to calculate solar dawn, noon, and dusk. These values are stored in an array so that the clock can be adjusted to solar time. One could also

store daily sums of irradiance, ambient temperature and AC power output. That would only take a kB or so and then build up daily performances, like above, without worrying about low light levels, etc. Once you have some data, you could do some linear regression/curve fitting. Linear regression should not take too much memory. As a final example, you could also store a day of 15-minute data and a month of daily sum data. You could multiply everything by 100 and store as integers to reduce code and memory requirements. Thus, it will be appreciated that various modifications, alternatives, variations, and changes may be made without departing from the spirit and scope of the invention as defined in the appended claims. It is, of course, intended to cover by the appended claims all such modifications involved within the scope of the claims.

CLAIMS

We Claim:

1. In a building that has an electrical load and that carries a solar powered electrical supply comprising an array of photovoltaic cells having a predetermined factory performance rating, apparatus comprising:

   (a) irradiance means, in solar communication with the array, for producing a signal representative of solar irradiance;

   (b) computation means, carried by said building and having a clock, for computing a running performance signal by using at least the predetermined performance rating, said irradiance signal, and a measure of the electrical power supplied to the load from the array;

   (c) a radio for broadcasting said performance signal; and

   (d) a substantially portable unit for receiving said performance signal from said radio and for visually displaying said performance signal.

2. The apparatus of Claim 1, wherein said solar powered electrical supply is characterized by a tilt, an azimuth, an outdoor temperature, and a geographic location; and wherein said computation means computes said running performance signal by using said irradiance signal, the predetermined performance rating, said measure of the electrical power supplied to the load from said array, and at least one of the geographic location of the building, the tilt of the array, the azimuth of the array, and outdoor temperature,

3. The apparatus of Claim 1, wherein computation means comprises a memory for recording a plurality of running performance signals as a function of time; and wherein said radio broadcast at least one historical performance signal from said memory and a running performance signal.

4. The apparatus of Claim 1, wherein said irradiance means comprises a solar cell having a predetermined electrical output as a function of its temperature; wherein said irradiance signal is transmitted by said radio; and wherein said portable

comprises a display that is a function of said irradiance signal.

5. The apparatus of Claim 1, wherein said running performance signal is a function of the difference between:

(a) a signal representative of electrical power supplied to the load from said array; and

(b) a signal representative of a calculation of the electrical power said array should produce as a function of time, said predetermined factory photovoltaic performance rating, and irradiance.

6. The apparatus of Claim 1, wherein said irradiance means is selected from the group consisting of silicon photodiode, a pyranometer, and a photoelectric cell.

7. The apparatus of Claim 1, wherein said running performance signal is a function of:

(a) the difference between electrical power supplied to the load from said array and what electrical power said array should produce as a function of current time, said predetermined factory photovoltaic performance rating, and said irradiance, and

(b) a predetermined maximum difference signal.

8. The apparatus of Claim 2, wherein said running performance signal is a function of:

(a) the difference between electrical power supplied to the load from the array and what electrical power said array should produce as a function of the geographic location, tilt and azimuth of the array, outdoor temperature, current time, said predetermined factory photovoltaic performance rating, and irradiance, and

(b) historical running performance signals stored in said memory.

9. The apparatus of Claim 3, wherein said historical running performance signals have been stored over at least several days.

10. The apparatus of Claim 3, wherein said historical running performance signals have been stored on the order of a year.

11. The apparatus of Claim 3, wherein said prior performance signals in said memory define a daily cycle; and wherein an alarm condition is created if a newly computed running performance signal does not fall within predetermined limits of said daily cycle for similar times of the day.

12. The apparatus of Claim 3, wherein said performance signals in said memory define a yearly cycle; and wherein an alarm condition is created if a newly computed running performance signal does not fall within a predetermined limit of said yearly cycle for similar dates of the year.

13. The apparatus of Claim 1, wherein said performance signal is computed at least every 30 minutes during day time.

14. The apparatus of Claim 1, wherein said radio broadcasts said measure of the electrical power supplied to the load from the array; and further including a display, on said portable unit, of electrical power from the array.

15. The apparatus of Claim 1, wherein said radio broadcasts, said irradiance signal, and said portable unit displays a solar irradiance.

16. The apparatus of Claim 14, wherein said load is connected to an electrical service supply; further including means for providing a measure of the electrical power supplied to said load by said service supply; and wherein said radio broadcasts said measure of electrical power supplied to said load by said service supply; and further including a display on said portable unit of electrical power consumed by the load from said electrical service.

17. The apparatus of Claim 16, wherein said compulation means computes the percentage of power consumed by the load and provided by the array relative to power consumed by the load and provided by said electrical service.

18. The apparatus of Claim 15, wherein said displya of solar irradiance is a depiction of the percent of measured solar irradiance relative to maximum solar irradiance.

19. The apparatus of Claim 15, wherein said display of solar irradiance is depicted by N icons where each icon represents (100%)/N of maxiumum solar irradiance.

20. The apparatus of Claim 14, wherein said electrical power from the array is depicted as a function of time.

21. The apparatus of Claim 14, wherein said electrical power from the array is depicted as total watt-hours consumed.

22. The apparatus of Claim 14, sherein said electical power from the array is depicted as total watt-hours produced during the current day.

23. The apparatus of Claim 22, wherein saved electical power from the array is depicted as a percent of maximum capacity.

24. Apparatus, comprising:

(a) a generally fixed unit that is adapted to be located in a building to which an electrical utility supplies electricity to a load, said building having a roof carrying photovoltaic cells supplying electricity to said load, an outdoor temperature, and a geographic location, said unit being adapted to receive a signal

that is representative of electrical power consumed by said load and provided by the utility, a signal that is representative of photovoltaic electrical power consumed by said load, a first signal that is representative of said outdoor temperature, a second signal that is representative of said geographic location, a third signal that is representative of solar irradiance on said roof, a fourth signal representative of the azimuth of said roof, a fifth signal representative of the pitch of said roof, and a signal that is representative of time; a processor within said unit using at least said first, second, third, fourth and fifth representative signals and time to derive a computed signal that is representative of expected power output of said photovoltaic cells, said unit including a relatively short range radio for broadcasting information that is representative of at least said computed signal: and

(b) a substantially movable unit for receiving said information broadcasted from said radio and for visually displaying at least a representation of photovoltaic power consumption and a representation of said computed signal.

25. The apparatus of Claim 24, wherein said movable unit includes a display of the photovoltaic power relative to utility provided electrical power, said display operating in response to information broadcast by said radio.

26. The apparatus of Claim 24, wherein said movable unit includes a display of photovoltaic power on a time scale.

27. The apparatus of Claim 24, wherein said second signal, said fourth signal, said fifth signal are preset.

28. The apparatus of Claim 27, wherein said first signal is preset.

29. A monitor for a structure that is carried by the earth, that has a photovoltaic electrical supply on its exterior, that is adapted to receive a primary electrical supply, that has an electrical load adapted to be connected to the primary power supply and to the photovoltaic power supply, that has an exterior temperature and that has a geographic location, comprising:

(a) a generally stationary unit comprising:

(i) photovoltaic means, operatively connected to the photovoltaic electrical supply, for producing a signal representative of photovoltaic power consumed by the load;

(ii) irradiance means, located on the exterior of the structure, for producing a signal representative of solar irradiance relative to the photovoltaic electrical supply;

(iii) computation means, receiving signals representative of the outdoor temperature, solar irradiance, geographic location, and time, for repeatedly producing a signal representative of the expected photovoltaic electrical power output;

(iv) means for producing an output signal that is a function of the difference between said expected photovoltaic electrical power output and actual photovoltaic electrical power consumption; and

(v) radio means for broadcasting information that is a function of photovoltaic electrical power output, said irradiance signal and said output signal; and

(b) a generally movable unit for receiving said information from said radio means and for visually displaying photovoltaic electrical power consumption, solar irradiance and said output signal.

30. The monitor of Claim 29, wherein said stationary unit receives a signal representative of the primary power consumption and sends it to said radio means; and wherein said movable unit displays primary power consumption in digital form.

31. The monitor of Claim 29, wherein said movable unit displays in digital form photovoltaic power consumption as a function of time.

32. The monitor of Claim 29, wherein said movable unit displays as a step function photovoltaic power consumption.

33. The monitor of Claim 29, wherein time is provided to said computation means by a clock; and wherein said computation means includes a memory for storing signals representative of the photovoltaic electrical power consumption, outdoor temperature, said output signal, and time from said clock.

34. The monitor of Claim 29, wherein said radio unit receives said signal representative of outdoor temperature, and said movable unit displays outdoor temperature.

35. The monitor of Claim 29, wherein said radio unit receives a signal representative of primary power consumption, and said movable unit displays primary power consumption.

36. The monitor of Claim 27, wherein said output signal is also function of historic deviations between said expected photovoltaic power output and photovoltaic electrical power consumption.

37. The monitor of Claim 29, wherein said stationary unit displays: in digital form primary power consumption, and said photovoltaic power output; photovoltaic power output as a function of time; and said output signal as a step function.

38. The monitor of Claim 36, wherein said historical deviations are computed over an interval of at least 24 hours.

39. The monitor of Claim 36, wherein said historical deviations are over an interval of at least 365 days.

40. The monitor of Claim 36, wherein said computation means comprises a plurality of differences over multiple twenty-four hour periods and computes the differences in time for the same difference between successive twenty-four hour periods to derive a correction signal for said clock.

41. The monitor of Claim 29, wherein said irradiance means comprises a solar cell.

42. An energy monitor adapted for use in home having a geographic location an electrical load and a roof that carries a solar electrical power supply, comprising:

(a) first power means, connected to the home's solar electrical power supply, for producing signals representative of power consumed by the load from said solar electrical power supply;

(b) irradiance means for producing a signal representative of solar irradiance;

(c) computation means, utilizing the geographic location of the home and time and said signal representative of power consumed by the load from said solar power supply and said solar irradiance signal, for producing an output signal representative of the efficiency of said solar electrical power supply;

(d) a radio transmitter for broadcasting information representative of the signals produced by said power means, and said computation means; and

(e) portable means, spaced apart from said radio transmitter, for receiving information from said radio transmitter and for visually displaying generated power consumption, solar power

consumption, solar irradiance and efficiency of said solar power supply.

43. The energy monitor of Claim 42, further including second power means connected to the homes utility service for producing, as an output, signals representative of power consumed by the load from said utility service.

44. The energy monitor of Claim 43, wherein said signals representative of power consumed by the load from said utility service are sent to said radio transmitter and received by said portable means for display thereon.

45. The energy monitor of Claim 42, wherein said computation means and said radio transmitter are housed together.

46. The energy monitor of Claim 42, wherein said computation means comprises: digital memory means using said geographic location and time, for computing the expected output power of the solar electrical power supply; and means for storing said expected output power in memory.

47. The energy monitor of Claim 46, wherein said computation means comprises a clock providing digital time signals; and wherein said memory stores, expected output power and solar electrical power consumption in the form of a time log.

48. The energy monitor of Claim 46, wherein the solar electrical power supply comprises an array of photovoltaic cells characterized by an azimuth, a tilt and a factory performance rating; and wherein said computation means produces said output signal as a function of a present value of azimuth, tilt and factory performance rating.

49. In a habitat that is carried by a platform orbiting a star, that has a photovoltaic electrical power supply on its exterior, that has a source of primary electrical power supply; that has an electrical load adapted to be connected to the

primary power supply and to the photovoltaic power supply, and that has an exterior temperature, apparatus, comprising:

(a) a substantially fixed unit that is adapted to receive:

(i) a signal representative of photovoltaic electrical power consumed by the load,

(ii) a signal representative of solar irradiance for the photovoltaic electrical power supply, and

(iii) a signal from a clock that is representative of time,

said fixed unit comprising a radio for transmitting information that is a function of signals (i) through (iii) and a signal that is representative of the performance of the photovoltaic electrical power supply and that is derived at least from signals (i) through (iii); and

(b) a receiver that is substantially movable for receiving said information, from said radio and for visually displaying time, photovoltaic power consumption, and said performance signal.

50. The apparatus of Claim 49, wherein said photovoltaic power supply comprises an array of photovoltaic cells, and said array is characterized by a predetermined geometry relative to the habitat including an azimuth and tilt; wherein said habitat has a predetermined geographic position relative to said orbiting platform, and said platform has a predetermined orbital path relative to said star; and further including means for providing a signal representative of the performance characteristic of said photovoltaic cells; and further including a processor that is adapted to use said signal representative of solar irradiance and said signal representative of the performance characteristic of said array and said tilt and azimuth and said geographic position, time and orbital path, and to derive said signal representative of the expected electrical power output.

51. The apparatus of Claim 24, wherein wherein said movable unit includes a display of solar irradiance that is a function said third signal.

52. The apparatus of Claim 1, wherein said solar powered electrical supply is characterized by an ambient temperature; and wherein said computation means computes said running performance signal by using said irradiance signal, the predetermined performance rating, said measure of the electrical power supplied to the load from said array, and ambient temperature,

53. The apparatus of Claim 1, wherein said running performance signal is a function of the difference between a number whose value is derived from a signal representing electrical power supplied to the load from the array, and a number whose value is derived from a signal representing solar irradiance.

54. The apparatus of Claim 53, wherein said number whose value is derived from a signal representing solar irradiance is at least a function of the product B and Gi^2 where Gi represents solar irradiance, and B is a predetermined constant.

55. The apparatus of Claim 53, wherein said number whose value is derived from a signal representing solar irradiance is at least a function of the product of A and Gi where Gi represents solar irradiance and A is a predetermined constant.

56. The apparatus of Claim 53, wherein said number whose value is derived from a signal representing solar irradiance is at least a function of the sum of the product of A and Gi and the product of B and Gi^2 where Gi represents solar irradiance, A is a predetermined constant and B is a predetermined constant.

57. The apparatus of Claim 53, where said performance signal is visually displayed on said portable unit by means of a lamp that is lighted if said difference is greater than a predetermined amount.

58. The apparatus of Claim y, where said performance signal is visually displayed on said portable unit by means of a lamp that is lighted if said difference is less than or equal a predetermined amount.

59. The apparatus of Claim 57, where said predetermined difference is 50%.

60. The apparatus of Claim 57, wherein said running performance signal is also a function of a disparity between:

(a) a number whose value is derived from a signal representing solar irradiance and whose value increases with increasing sunlight, and

(b) a predetermined number representative of daytime irradiance; and

wherein said lamp is lighted if said difference is greater than a predetermined amount and said disparity is sufficiently high to indicate a daylight condition.

61. The apparatus of Claim 52, wherein said running performance signal is a function of the difference between a number whose value is derived from a signal representing electrical power supplied to the load from the array, and a number whose value is derived from a signal representing ambient temperature.

62. The apparatus of Claim 61, wherein said number whose value is derived from a signal representing ambient temperature is a function of the product of C and T_{amb} where T_{amb} represents ambient temperature and C is a predetermined constant.

63. The apparatus of Claim 52, wherein said running performance signal is a function of the difference between a number whose value is derived from a signal representing electrical power supplied to the load from the array, and a number whose value is derived from a signal representing solar irradiance and a signal representing ambient temperature.

64. The apparatus of Claim 52, wherein said running performance signal is a function of a number whose value is derived from a signal representing solar irradiance and a signal representing ambient temperature.

65. The apparatus of Claim 64, wherein said number whose value is derived from a signal representing solar irradiance and a signal representing ambient temperature is derived in part by computing:

(a) the product of C and T_{amb} where T_{amb} represents ambient temperature and C is a predetermined constant.

(b) the product of A and Gi and

(c) the product of B and Gi^2

where Gi represents solar irradiance, A is a predetermined constant, and B is a predetermined constant.

66. The apparatus of Claim 65, wherein said number whose value is derived from a signal representing solar irradiance and a signal representing ambient temperature is derived in part by computing $AGi + BGi^2 + CGiTam$ where Gi represents solar irradiance, where Tam represents ambient temperature, and where A, B and C are predetermined constants.

67. The apparatus of Claim 53, where A is about 0.8, B is about 0.1 and C is about -0.0045.

68. The apparatus of Claim 52, wherein said computation means computes said running performance signal is a function of the form $Gi * (A + B*Gi + C*Tam)$. where Gi represents solar irradiance, where Tam represents ambient temperature, and where A, B and C are predetermined constants.

Abstract of the Disclosure

A method and apparatus is disclosed for monitoring the performance of a solar powered electrical supply where the supply comprises an array of photovoltaic cells that are mounted on a building. In one embodiment, the apparatus comprises: irradiance means for producing a signal representative of solar irradiance; computation means for computing a running performance signal by using at least the irradiance signal, temperature, and a measure of the electrical power supplied to the load from the array; a radio for broadcasting the performance signal; and a portable unit for receiving the performance signal from the radio and for visually displaying the performance signal, power production, and electrical utility usage.

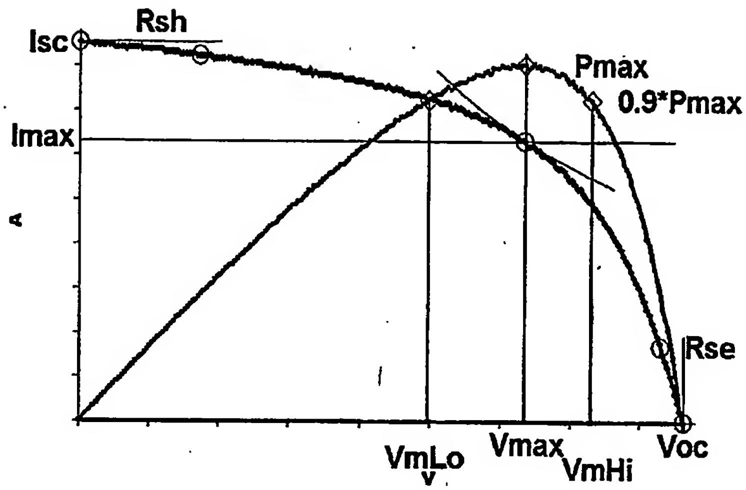
Isc
Rsh
Pmax
0.9*Pmax
Imax
A
Rse
VmLo
V
Vmax
VmHi
Voc

FIG. 1

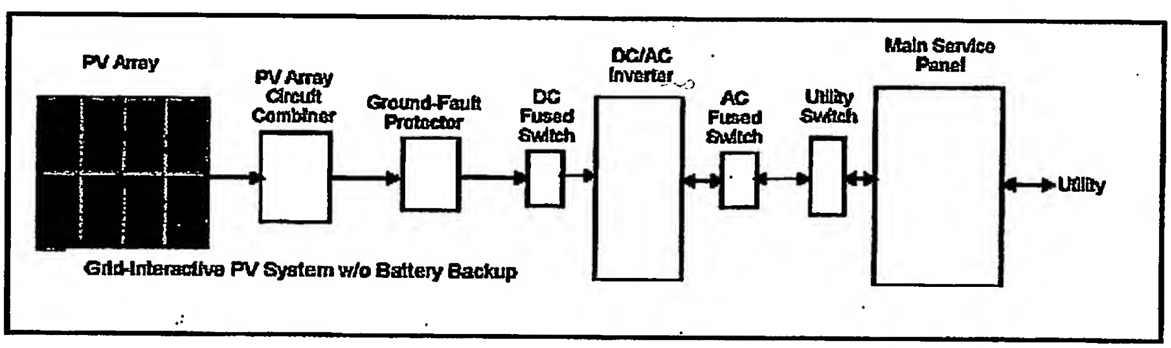
PV Array
PV Array Circuit Combiner
Ground-Fault Protector
DC Fused Switch
DC/AC Inverter
AC Fused Switch
Utility Switch
Main Service Panel
Utility
Grid-Interactive PV System w/o Battery Backup

FIG. 2

PV system output (now)

household consumption

PV system output/consumption

sunlight intensity

PV system energy production for day

PV system energy production for day

PV system energy production for daylight hrs

time

outdoor temperature

PV cumulative energy production lifetime

system status

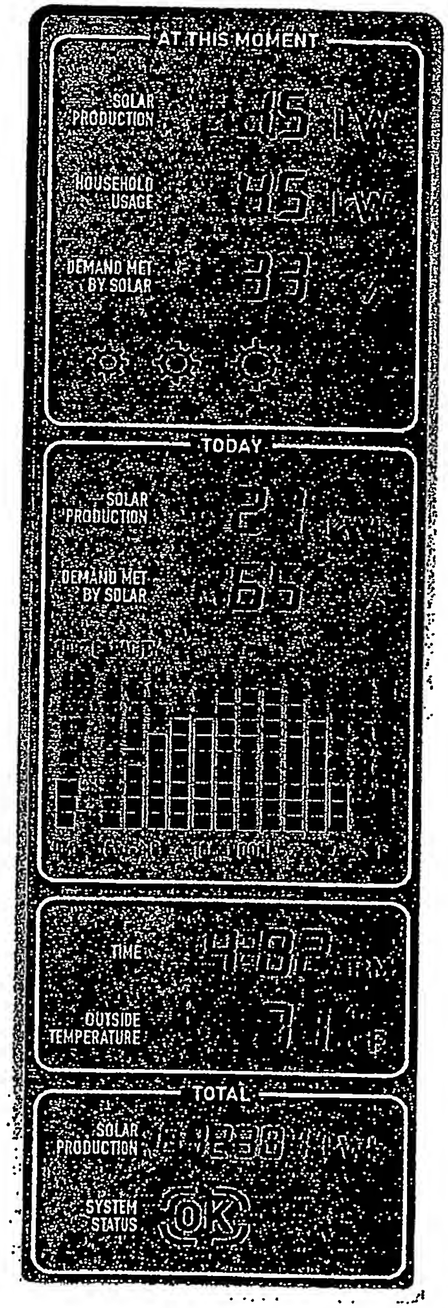

FIG. 3

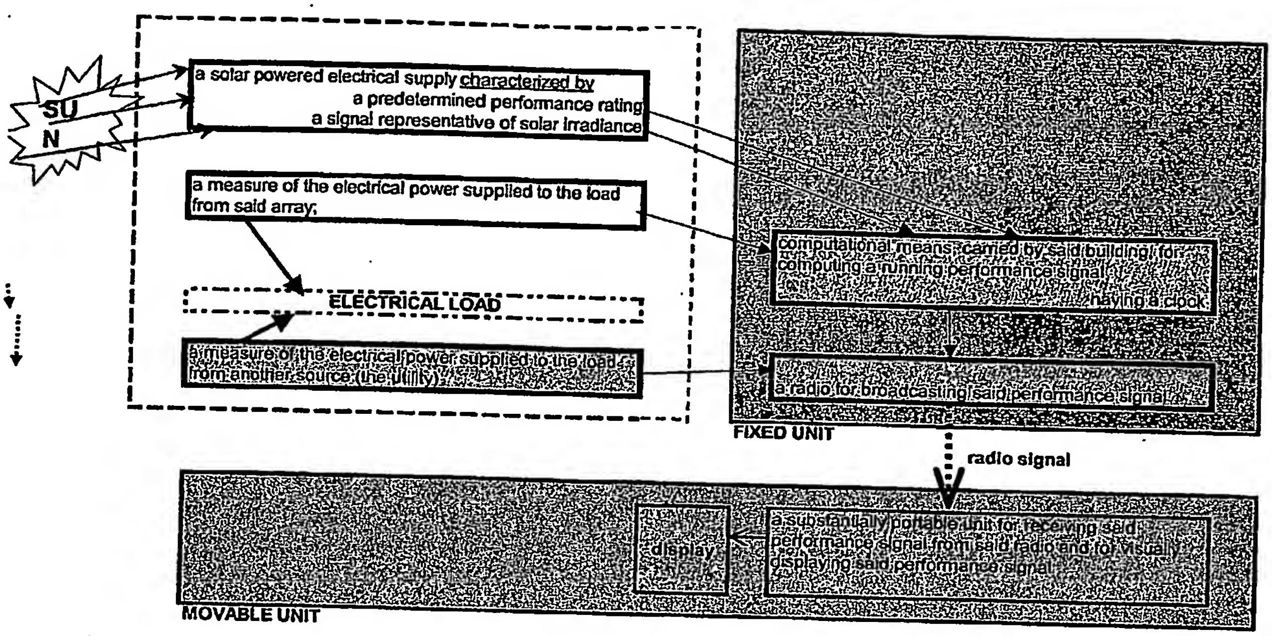
SUN
a solar powered electrical supply characterized by
a predetermined performance rating
a signal representative of solar irradiance
a measure of the electrical power supplied to the load from said array;
ELECTRICAL LOAD
a measure of the electrical power supplied to the load from another source (the utility)
computational means carried by said building for computing a running performance signal
having a clock
a radio for broadcasting said performance signal
FIXED UNIT
radio signal
display
a substantially portable unit for receiving said performance signal from said radio and for visually displaying said performance signal
MOVABLE UNIT

FIG. 4

5

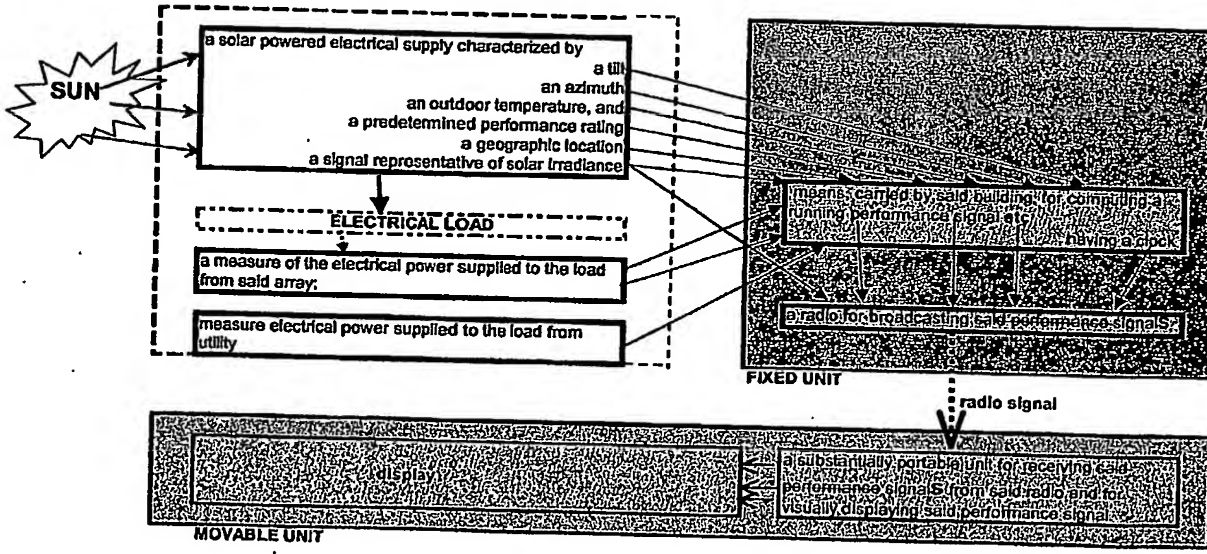
SUN
a solar powered electrical supply characterized by
a tilt
an azimuth
an outdoor temperature, and
a predetermined performance rating
a geographic location
a signal representative of solar irradiance
ELECTRICAL LOAD
a measure of the electrical power supplied to the load from said array;
measure electrical power supplied to the load from utility
means carried by said building for computing a running performance signal etc
having a clock
a radio for broadcasting said performance signals
FIXED UNIT
radio signal
display
a substantially portable unit for receiving said performance signals from said radio and for visually displaying said performance signal
MOVABLE UNIT

FIG. 5

4/5

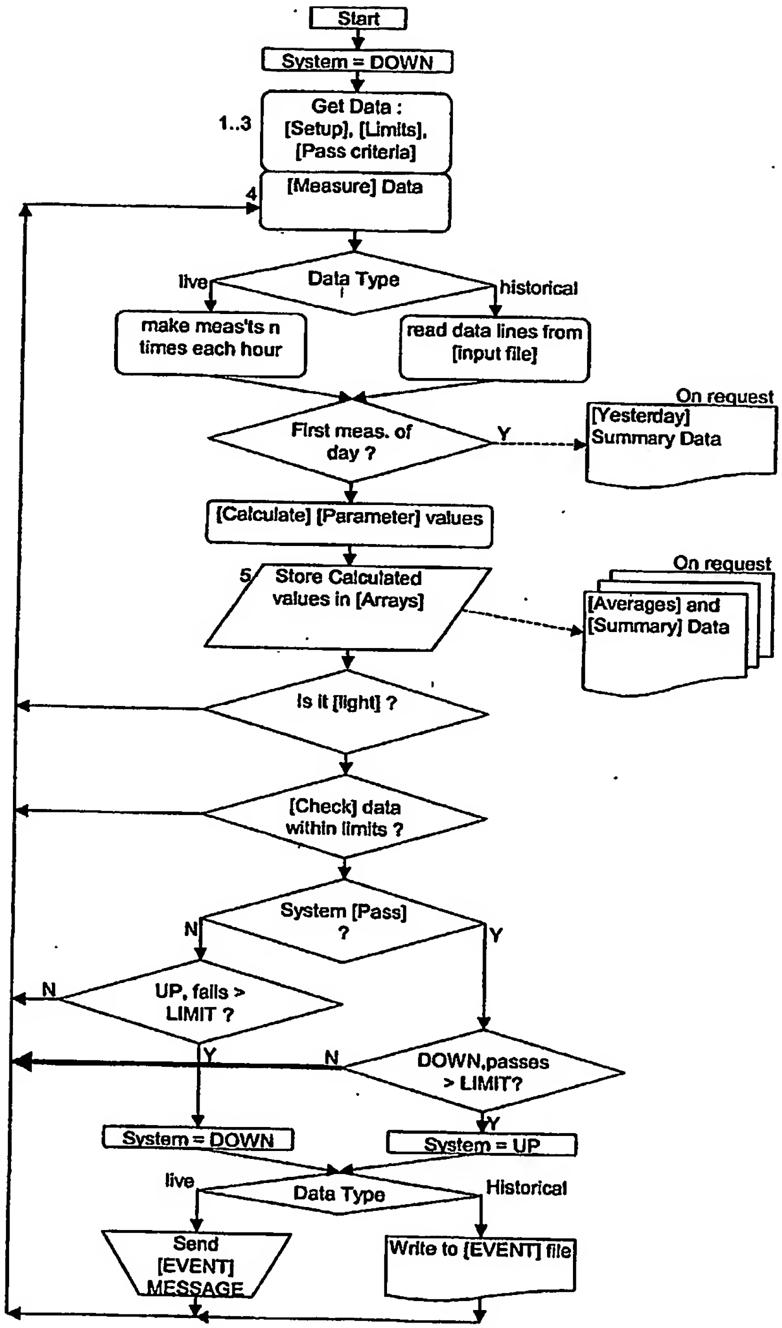
Start
System = DOWN
1..3
Get Data : [Setup], [Limits], [Pass criteria]
4
[Measure] Data
live
Data Type
historical
make meas'ts n times each hour
read data lines from [input file]
On request
First meas. of day ?
Y
[Yesterday] Summary Data
[Calculate] [Parameter] values
5
Store Calculated values in [Arrays]
On request
[Averages] and [Summary] Data
Is it [light] ?
[Check] data within limits ?
System [Pass] ?
N
Y
N
UP, falls > LIMIT ?
Y
N
DOWN,passes > LIMIT?
Y
System = DOWN
System = UP
live
Data Type
Historical
Send [EVENT] MESSAGE
Write to [EVENT] file

FIG. 6

5

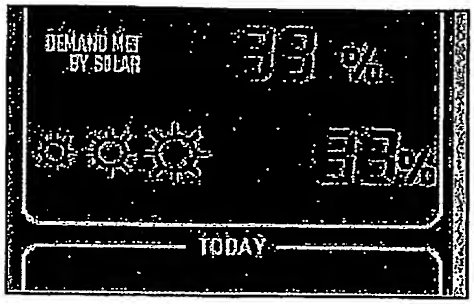

FIG. 7

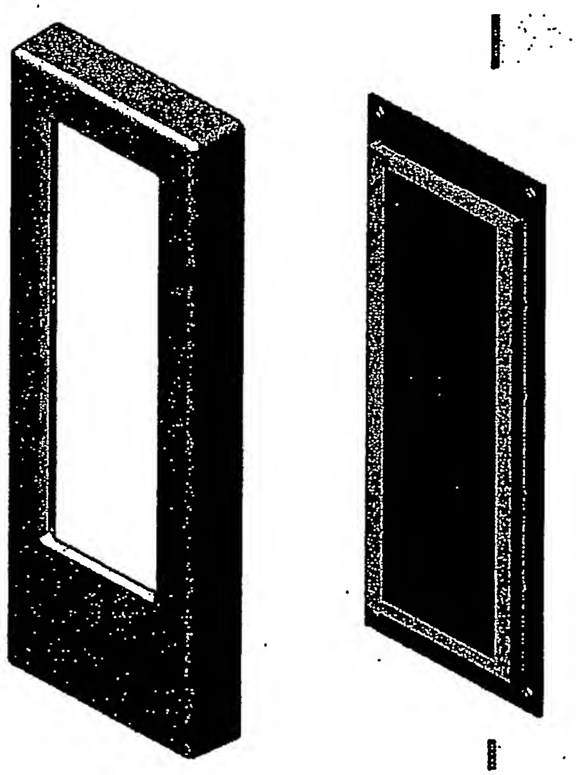

FIG. 8